

SYMPOSIUM

The Life and Legacy of Marie Curie^a

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Marie Curie was a remarkable woman whose discoveries broke new ground in physics and chemistry and also opened the door for advances in engineering, biology, and medicine. She broke new ground for women in science: she was, for example, the first woman to receive a doctor of science degree in France, the first woman to win Nobel Prize, the first woman to lecture at the Sorbonne, the first person to win two Nobel Prizes, and the first Nobel Laureate whose child also won a Nobel Prize. Her life offers insights into the changing role of women in science and academia over the past century. It also offers examples of many ways in which scientists can, and should, work to improve the educational programs and career opportunities available to those who follow in their footsteps.

This paper is based on a talk given at the *Marie Curie Nobel Centennial Symposium: Celebrating Women in Science*, at which The Yale community and their guests celebrated the centennial of Marie Curie's first Nobel Prize and the legacy that this remarkable scientist left to the women who followed her in the sciences. In this paper, I will talk about the life of Marie Curie [1-4], focusing on the challenges she faced, the barriers she breached, her skills, and her activities (both heralded and unsung) that we should emulate and should encourage in the young women we mentor.

MARIA'S CHILDHOOD

Maria Salomea Sklodowska was born in Warsaw, Poland, November 7, 1867. She was the youngest of the five children of Bronislawa and Wladyslaw Sklodowski. Maria came from an interesting and unusual family. Her parents were both from families of the minor Polish nobility, who had been stripped of their lands and political powers after the defeat of Poland by Czarist Russia. At the time of Maria's birth, the January uprising of 1864 had recently been crushed, and the city of Warsaw lay under brutal occupation. One of Bronislawa's brothers had

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been exiled to Siberia; another had been wounded twice in the war and had escaped to France. The harsh political repression of the occupation affected the life of the Sklodowski family deeply, and its shadow remained throughout Maria's life.

Both of Maria's parents came from highly educated families that valued rigorous and comprehensive education for girls as well as boys. Maria's grandfather had been considered very radical, because he had risked his job as school principal by insisting that "talented peasants" should be educated along with the children of the nobility. Little Maria was born into a family that expected its children, both girls and boys, to be serious and rigorous in their studies, to continue their education throughout their lives, to have meaningful careers, and to pass their knowledge on to others, regardless of the rewards or risks incurred in doing so.

Maria's mother had been educated at the Freta Street School, the only private girls' school in Warsaw at the time. After graduation she remained at the school as a teacher and soon became headmistress. From 1860 until 1868, the family lived at the school, in the apartment reserved for the headmistress. Here Bronislawa bore and cared for her five children, while running the school, teaching, and caring for her brother-in-law, who was dying of tuberculosis.

In 1868, Maria's father Wladyslaw was promoted to the position of headmaster of the public school where he taught, and the family moved into the headmaster's apartment. Maria's mother resigned from her position to care for her family and because of her failing health. To stretch Wladyslaw's meager salary, she made the family's clothes (including their shoes) and took in student boarders. Maria's childhood saw many hardships. Maria's father was demoted from his headmaster position by the Russian government for his political views and for the family's connections to "revolutionaries."

Maria's oldest sister contracted typhus and died when Maria was 11. Her mother, who had suffered from tuberculosis for many years, died from this disease soon afterward.

Nevertheless, the family was determined that the children should get the best education possible. Maria, like her siblings, was sent to a combination of public and private schools where she was rigorously educated in several languages, mathematics, and the sciences. Her education included intensive training in Polish language, literature, and history, despite the fact that such education was illegal. Public mention of the lessons she learned as a child at school and at home could have resulted in the arrest and exile of her teachers and family. Maria appears to have been a brilliant child, with a great gift for languages and an extraordinary memory. She graduated from the gymnasium at the age of 15 and, like her older brother and sister, she was first in her graduating class and received many academic awards.

THE GOVERNESS YEARS

There was no chance of further formal education. No university in Warsaw, or in Poland, admitted women. Her father, barely able to support his son in medical school in Warsaw, certainly did not have the means to send any of his three surviving daughters to study in Paris or St. Petersburg, where some universities were open to women. Maria and her sister Helena, therefore, did the logical thing after graduating: they left to visit the country homes of relatives and family friends, and apparently spent an entire year traveling and partying.

They then returned to Warsaw and began to work as private tutors, one of the few intellectual jobs open to women. They also enrolled in courses in a clandestine university for women, called the Flying University. This illegal school organized

scholars and scientists to meet with small groups of women students secretly in apartments, homes, and shops, to provide an advanced education, which had been outlawed for women in Poland under the Russian occupation.

Maria and her older sister Bronia came up with a plan for escaping from this situation. Bronia would use their meager savings to leave immediately for Paris, where she would study medicine. Maria would take the most lucrative governess position she could find. She would use her wages to support Bronia while she studied. When Bronia finished medical school she would, in turn, support Maria while she studied in Paris.

For the next three years, Maria worked as a live-in governess in a small and isolated village in rural Poland. She taught the family's three children (a baby, a 6-year-old, and an 18-year-old girl). She also organized clandestine classes, in Polish, for the peasant children of the village. Both teaching peasants to read and teaching Polish language, culture, and history were illegal acts, punishable by exile to Siberia. Maria also continued to study and read voraciously. During this time, Maria and the family's oldest son Kazimierz, a student at Warsaw University about two years older than Maria, apparently decided that they were in love and announced their intention to be married. The parents, however, were outraged that their son would think of marrying a penniless governess and forbade the marriage. The relationship apparently waxed and waned, always with the total disapproval of his parents, even after Maria returned to Warsaw to accept a new governess position and to recommence her studies at the Flying University.

During this time in Warsaw, Maria, for the first time, had an opportunity to perform laboratory research. Her cousin, Jozef Buguski had returned to Warsaw after studying in Russia with Mendeleev

to direct the Museum at the Ministry of Industry and Agriculture. Under his tutelage, Maria secretly began to study wet bench chemistry, performing experiments in the chemistry laboratory that formed part of the museum collection. It was during this period that Maria discovered her love of and talent for experimental laboratory research.

PARIS

Bronia, in the meantime, married, graduated from medical school, and opened a practice in Paris. She wrote repeatedly to Maria, urging her to come to Paris; Maria hesitated for some time, apparently torn between her desire to study in France and her ties to Poland, which included her concern for her father and her younger sister, her continuing affection for Kazimierz, and her reluctance to leave her beloved homeland. In 1891, Maria, now 23, went to Paris and enrolled at the Sorbonne. She first lived with Bronia and

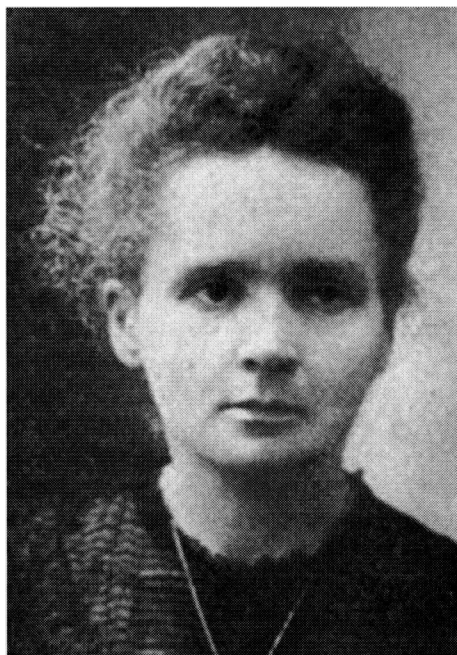


Figure 1. Marie Curie. (The Frontier Press Company.)

her husband in the small apartment that also served as the office of these two physicians, but found that the distractions of the crowded apartment/office made studying difficult and that the long trip to the University was exhausting and expensive. She moved to a small attic room near the University. This was a very daring thing to do. In this era in Paris, proper young ladies did not leave their houses without an escort and would not think of entering a restaurant or a café alone, much less walk alone through the streets of the Latin Quarter where Marie's new apartment was located.

There were few women among her fellow students. Although the universities of France were nominally open to women, it was nearly impossible for women educated in France to gain admission. The girls' schools in France did not offer the physics, biology, Latin, and Greek needed to pass the baccalaureate exam, which was required for entry into the University. Most of the 210 women at the University when Marie enrolled were, therefore, foreign. There were about 9,000 men. In 1893, when Maria received her Licence des Sciences, equivalent to a Master of Science, she was one of only two women recipients in the University. She was one of five women licencees when she received her licence in mathematics in 1894.

During this period, Maria, who had registered at the Sorbonne using the French form of her name, "Marie," studied with some of the greatest scientists of the day in France. She was a brilliant student, placing first on the exam for the degree in science and second on the exam for the degree in mathematics. Finances continued to be a problem. Marie's family could offer only meager financial support and her own small savings had been nearly exhausted by the cost of her trip to Paris, and she lived on a budget of 3 francs a day [1]. Marie, therefore, lived in the cheapest of student apartments, with the barest of

necessities, and no luxuries whatsoever. She might not have completed her mathematics degree had a friend not arranged for her to receive a 600-ruble Alexandrovitch scholarship, which allowed her to continue her studies for this final year.

Although some biographies imply that Marie had no life outside the classroom, her correspondence and the memoirs of others clearly show that she socialized with family and friends in Paris, took long summer vacations to visit her family in Poland and even seems to have become romantically involved with a fellow student, known from their correspondence only as M. Lamotte. This romance ended, as did her plans to return permanently to Poland after receiving her degrees, when she met Pierre Curie in the spring of 1894.

PIERRE CURIE

Pierre Curie was born in Paris in 1859. His father, a doctor from a family of Protestant scientists and physicians, had participated in many of the riots and rebellions of this period in French history. Pierre's life and schooling were unconventional. Because his father feared that Pierre's way of learning and thinking was not compatible with the teaching methods of the French school system, Pierre was educated at home, by his father and by tutors. He matriculated into the University at age 16, received his Licence des Sciences at the age of 18, and immediately joined the Sorbonne as a "preparateur" or research assistant in the physics laboratory. He began to perform and publish original research almost immediately, first with his mentor Paul Desains and then with his brother Jacques Curie. The Curie brothers performed seminal research on symmetry in crystals and discovered the phenomenon of piezoelectricity, which underlies the use of crystals in a variety of applications including microphones, sonar, balances, and the detection of radia-

tion. In 1882, Pierre left the Sorbonne to become a laboratory supervisor at the Ecole Municipale de Physique et Chemie Industrielles in Paris. Here he developed the analytic balance and performed celebrated research on magnetism.

Pierre Curie's scientific brilliance earned him an international scientific reputation for the incisiveness of his research and thinking, for the precision of his experimentation, and for the fine analytic instruments he made for use in his research. However, he was very much an outsider in the French scientific establishment. He had not attended the "appropriate" schools. Moreover, he had absolutely no interest in the rituals of science and academia. Despite performing and publishing work that would have been more than sufficient for his doctorate, he never bothered to write a thesis and obtain his degree. As a result, when he met Marie in 1884 he had been in his position at the very bottom of the academic ladder at an unprestigious trade school for 11 years.

COURTSHIP AND MARRIAGE

Marie and Pierre were introduced by mutual friends. The husband, a physics professor from Poland, knew Pierre and his work; his new bride had been an acquaintance of Marie's during her years as a governess in Poland. The dinner to which Pierre and Marie were invited in the spring of 1884 apparently generated spirited scientific discussions. These escalated rapidly during Marie's last few months in Paris into a scientific relationship (beginning with Pierre sending Marie reprints of his scientific papers), then progressing to exchanges of more personal letters and visits, and eventually to Pierre's suggestion that Marie not remain in Poland after completing her exam, as she had planned, but instead return to Paris and move into an apartment on the Rue Mouffetard with him.

Marie did return to Paris but moved into an apartment attached to her sister Bronia's office. Marie began to perform her research on the magnetic properties of steel in a converted storage room in Pierre's modest laboratory space. During the next year, Pierre wrote up his long-delayed thesis and was immediately given a professorship at the Ecole.

On July 26, 1895, Pierre and Marie were married in Paris, in a simple ceremony attended by both of their families. As a wedding present, they bought bicycles, and went bicycling through the countryside of Brittany. A delightful photo taken on their honeymoon [1] shows the happy couple. Marie is often described as being somber and unfashionable, but in this photo her bicycle is decorated with flowers and she is wearing the height of shocking 1895 bicycling fashion: a very trendy brimmed boater hat, knickers, and stockings that reveal the shape of her legs.

After their honeymoon, Marie and Pierre moved into a modest three-room apartment on Rue de la Glaciere, overlooking a garden, but furnished simply, almost starkly with furniture borrowed from their families. They made an effort to keep their lives simple, allowing them to focus on their work in the laboratory. To quote Marie, "I am arranging my flat little by little, but I intend to keep it to a style which will give me no worries and will not require attention, as I have very little help: a woman who comes in for an hour a day to wash the dishes and do the heavy work. I do the cooking and housekeeping myself" [1]. In this as in many other things, the Curies defied the convention of Parisian society of the belle époque by focusing on practicality, not on appearances. They reserved their few discretionary funds for the things that mattered to them, such as a little help with the heavy household work, their bicycles, day trips, weekends and vacations in the countryside, and flowers.

DISCOVERY OF RADIOACTIVITY

In the laboratory, Pierre and Marie continued to perform research on magnetism, as a team, for the next three years. Their research took a dramatic turn in December 22, 1895, when Conrad Roentgen released his paper announcing the discovery of X-rays. This paper was telegraphed around the world the same day. Scientists and the public were fascinated. In Paris, Henri Poincaré reported to the French Academy of Sciences on January 20, 1896, that X-rays produced phosphorescence not only on the glass walls of the tube but also on a screen coated with a phosphorescent substance. Henri Becquerel was fascinated by the report and began to explore the idea that phosphorescent substances also produced X-rays. In the next few weeks he reported that of the many phosphorescent materials he tried, only uranium salts produced these rays, and that it did not matter whether the uranium was in a phosphorescent chemical form or whether it was exposed to light. Becquerel then seems to have lost interest in this phenomenon and instead turned to work with X-rays.

It was William Thomson, Lord Kelvin, who stirred the Curies' interest in Becquerel's "uranium rays" by showing in an experiment using an electrometer that Pierre Curie had made for him, that uranium rays, like Roentgen's X-rays, "electricified" the air. The timing of Kelvin's paper was fortuitous. Marie and Pierre's first child, Irene, had been born September 12, 1897, after a difficult pregnancy. Marie, who had spent much of the summer in Brittany, was now back in the laboratory and eager to work on a new subject, which could be used for her doctoral thesis.

It would be easy to underestimate the resolution behind this decision. No woman in Europe had yet completed a doctorate, although Elsa Neumann, in Germany, was well into her thesis in electrochemistry. Most of the Curie's contemporaries doubt-

ed that Marie, a frail young wife and new mother, would ever complete her thesis.

The approach Marie used rested completely on measurements of radioactivity using the highly precise piezoelectric balances and electrometers that Pierre had developed. Pierre was clearly involved in this project from its earliest stages, as shown by the interchanging handwriting in their laboratory notebook. Their collaborations were to continue in this same vein, with the two researchers working together as intellectual collaborators on some elements of the research, serving as technicians for each other in other studies, and each taking sole responsibility for other elements and developing these independently or with other collaborators.

On April 12, 1898, the members of the Academy of Sciences heard a report written by Marie Skłodowska Curie, entitled "Rays emitted by uranium and thorium compounds." Because neither Marie nor Pierre was a member of the Academy, Marie's professor, Gabriel Lippman, presented the paper. The implications of this paper went well beyond the superficial conclusion that both pitchblende and chalcite produced ionization. First, Marie concluded that the activity she was measuring was an atomic property, not a molecular property, because the uranium activity did not depend on the chemical state of the uranium and because the level of the activity was always proportional to the amount of uranium in the compound being tested. Second, she introduced the concept that a new, unknown element could be discovered by showing that its radioactivity was different from that of any known element.

RADIUM AND POLONIUM

Marie and Pierre set out to isolate this new element. Because the amount of the mystery material in their samples was far too small to detect by spectroscopy or chemical tests, they measured their

progress in purification by measuring the ionizing activity of the products. Here again, we see a new concept: the idea that the purification of a new material could be guided by measuring the radioactivity in the reaction products. This concept has since become familiar to biologists purifying radiolabeled biomolecules, as well as to chemists.

On July 18, 1899, Henri Becquerel read to the Academy of Sciences the paper by Pierre and Marie Curie "On a novel radioactive substance contained in pitchblende." This paper attracted immediate attention. Later in July, the Academy awarded to Marie a 3,800 franc prize, citing both her work on the magnetic properties of steel and her July paper suggesting the existence of a new element in pitchblende. Interestingly, although the Academy did break tradition by awarding this prize to a woman, they couldn't quite bring themselves to communicate this news to her directly. Instead Henri Becquerel and Marcelin Berthelot wrote letters to Pierre, informing him that Marie had won the prize. Becquerel's letter ends, "I congratulate you sincerely, and beg of you to present my respectful compliments to your wife" [2].

Immediately afterward, the Curies left to summer in the volcanic mountains in the Midi of France and did not return to Paris until mid-November. They were not totally inactive during the summer: Marie had ordered a very large shipment of pitchblende, which they began to attack immediately upon their return to Paris.

Pierre's laboratory was too small for this massive purification project, and the fumes, chemicals, and metals released during the purification procedure were too toxic to work with in an enclosed space. The University provided them with an additional facility, a storage shed with an open courtyard. This shed lacked electricity, was open to the weather, and was an exceedingly primitive facility even by the



Figure 2. Marie, Irene, and Pierre Curie. (The Century Company).

standards of the day. Here Marie undertook the formidable task of isolating, purifying, and characterizing Polonium and Radium. This task required many years and the donation by the Austrian government of over 10 tons of pitchblende.

Although the shed and the adjacent laboratory were primitive, minimally furnished, and dreary, the facility did have a property that gave the Curies great pleasure: it glowed from the luminescence of the highly radioactive materials. To quote Marie, describing their evening visits to the laboratory, "Our precious products, for which we had no shelter, were arranged on tables and boards; from all sides we could see their slightly luminous silhouettes, and these gleamings, which seemed suspended in the darkness, stirred us with ever new emotion and enchantment" [2]. It is not surprising, in retrospect, that both of the Curies began to exhibit signs of ill health, ranging from fatigue and anemia to chronic, painful "burns" to the skin of their hands, and weakness and movement problems in their hands and legs.

The purification of the new elements Radium and Polonium progressed. Over the next few years, Marie published 19 papers describing various aspects of her thesis research, ten with Pierre as co-author. In addition, Pierre published 14 additional papers on other aspects of

radioactivity. On May 11, 1903, Marie submitted her thesis, which she defended successfully on June 12, 1903, receiving the degree of *Docteur des Sciences Physiques* with the mention “*tres honorable*.”

The thesis was reprinted widely. Seventeen editions, in five different languages, were published in the first year after its defense, including an English edition published in London by the *Chemical News* [5, 6]. One of the interesting things about this groundbreaking thesis is that it reads smoothly and easily, either in French or in the English translation, which Marie prepared herself. Marie’s amazingly clear and simple writing style allows the implications of her complex science to be presented clearly to scientists unfamiliar with the details of the subject and even to non-scientists.

This was a period of scientific success for the Curies — and apparently a happy period as well. Pierre’s salary was modest in the extreme. Marie’s was truly minimal. They had made a deliberate decision to publish their data on the isolation and purification of Radium, rather than pursuing patents on the process. As a result, many companies made and sold radium, but no profits flowed to the Curies.

Both Marie and Pierre held part-time teaching positions to maintain their family. Both seem to have taken great pleasure in their teaching roles. Marie became the first woman to teach at the *École Normale Supérieure de Sevres*, France’s best preparatory school for woman teachers. She altered the Physics curriculum in her classes from one that emphasized reading and rote memory to a “hands on” science curriculum in which students designed, performed, analyzed, and interpreted experiments using equipment borrowed from research laboratories. Many of Marie’s students went on to become physicians, science teachers, scientists, and mathematicians. Marie invited her physics students to hear her defend her thesis.

They were reportedly proud to hear her respond to questions and delighted to hear that she received the mention “*tres honorable*.” Even Marie Curie’s own thesis defense became a part of her teaching and mentoring.

The Curies lived happily, but very modestly, in the outskirts of Paris, with their daughter Irene and Pierre’s widowed father, Eugene, who apparently relished being a grandfather and who provided stability to a household headed by two very intense, busy, and driven scientists. As with two-career couples today, Marie’s journals show that childcare (live-in nannies) and household help were continuing expenses, needed to enable the professional lives of the parents. The Curies also used their money for things they considered important — repaying the scholarship that had allowed Marie to finish her degree in mathematics, so that another Polish student could be sent abroad to study, and helping family and students with financial problems. None of the family appears to have had any interest whatsoever in the “appearances” of the household. The furnishings and decor in the household remained simple and minimal throughout Marie’s life, although flowers and gardens were always a priority. The family also lived simply. In a city where fashion, the Arts, and Society were valued, the Curie family relished quiet activities with family and friends — casual dinners, long walks, gardening, and bicycling in the country. They also spent long summer holidays in the country or on the coast, relaxing with academic and scientific colleagues as well as family members. Their letters remark on the “restorative” value of these vacations. Given their constant exposure to radiation in the laboratory, this was undoubtedly true. In August 1903, Marie’s health worsened after the miscarriage of her second child. She began to show signs of the anemia and lung problems that would persist for the rest of her life.

THE FIRST NOBEL PRIZE

The scientific world began to note the Curie's scientific accomplishments. In November 1903, the Royal Society of London presented them with the Davy Medal, for the most important discovery of the year in chemistry. While Pierre was in London accepting this award, Marie, too ill to travel, received word that they would share with Henri Becquerel the 1903 Nobel Prize in Physics for their "joint work concerning investigations of the radiation phenomena described by Henri Becquerel." Marie became the first woman to receive a Nobel prize.

These events raised the Curies to celebrity status. The moneys from these and subsequent prizes stabilized and simplified their personal and scientific lives: they hired a laboratory assistant, and they installed indoor plumbing in their home. They also used some of the money to provide a scholarship to one of Marie's students at Sevres and scholarships for students from Poland studying in Paris. They sent money to Maria's sister Bronia, who was establishing a tuberculosis clinic in Poland, and money to help other family members. They continued to live simply and modestly and, to the decreasing extent possible, privately. A chair in physics was created for Pierre at the Sorbonne. When Pierre told the University that the salary was inadequate to support him, and that he would need to retain his outside teaching job, the deputies added funds to support his laboratory, including a post of "Chef des Travaux," or Laboratory Chief, for Marie. The enhanced resources and the scientists eager to collaborate ensured that the Curie's research efforts remained at the cutting edge of the revolution occurring in physics. Their laboratory facilities, however, remained primitive. In addition, the Academie des Sciences, which had rejected Pierre's 1902 application for membership, admitted him in 1905 only by the narrowest of margins. The Curies were

never fully accepted into the French scientific establishment.

In 1904, Marie again became pregnant. Wary from her miscarriage the year before and still not fully recovered, she remained in the country until the birth of her second child, Eve, in December. It was not until the summer of 1905 that Pierre and Marie were in sufficiently good health to travel to Stockholm and receive their Nobel Prize. They then went to the beach for their summer vacation before returning to Paris and to their exhausting routine of research and teaching.

PIERRE'S DEATH

On April 19, 1906, disaster struck, when Pierre Curie, rushing through a heavy rain along the Rue Dauphine at the Pont Neuf intersection, stepped into the path of a heavily laden wagon and ran into the horses. As the horses reared up, he was flung under the wheels of the wagon and killed. The accident sent Marie into the depths of depression; it was months before she reassumed work in the laboratory and years before she recovered from this emotional blow. She was described by a friend, Marguerite Borel, as "dead to the world. She is a scientist wallowed in behind her grief" [2].

The Sorbonne was faced with a great problem: what to do about Pierre's chair, laboratory, and courses. No woman had even taught in or held a faculty position at the school, but Marie's credentials were hard to ignore. The school finally compromised on a solution. Pierre's chair was left vacant. Marie, as director of the laboratory, continued with her research. She also assumed Pierre's teaching responsibilities and became the first woman to lecture at the Sorbonne.

Her first lecture typifies her attitude toward this new position. Hundreds of people gathered hours before the lecture: reporters, photographers, celebrities, col-

leagues, scholars, and curious Parisians, as well as the students scheduled for Pierre's class and students from Marie's advanced physics class at Sevres, who had been granted permission to attend her lectures because she could no longer teach their course. Most attendees hoped for drama — a tribute to Pierre or at least a mention of the historic nature of the event. Marie instead entered the room quietly at the exact hour the class was to begin, dressed in a simple black dress, and began to lecture directly to her students on the scheduled introductory topic. Her lecture began with the understatement, "When one considers the progress in physics in the last decade, one is surprised by the changes it has produced in our ideas about electricity and about matter" [2].

Marie Curie took an active role in the teaching of her own children. She believed the programs of girls' schools were inadequate, not only because of the weaknesses in experimental science and mathematics, but also because of the lack of preparation in languages and classics and the lack of physical activity, which she viewed as essential for maintaining physical and mental health. She tutored Irene, whose interest and obvious talents in science and math she knew needed fostering in ways not well met by the standard curricula, and she ensured that Eve received training to develop her obvious language and musical talents. For a time, she and her scientific colleagues even ran a cooperative school for their children, with each one teaching his or her area of expertise. Recently discovered class notes taken by one of her students at this school show the rigorous demands made on the students and also the joy of the students with their curriculum and their growing laboratory skills [7].

Marie continued her research on radioactivity and radioactive elements, acquiring an ever-growing group of young scientists from around the world to work in her laboratory, with its primitive facili-

ties but cutting-edge science. Marie's research program was greatly enhanced by the gift from Andrew Carnegie of a \$50,000 endowment, which in 1906 was a small fortune, to fund "Curie Scholarships" for Marie's trainees.

In 1910, Marie emerged from the long depression that had followed Pierre's death into scandal, by having, or appearing to have, an affair with Paul Langevin, a physicist and longtime scientific colleague and friend of the Curies. Although estranged from his wife, Paul Langevin was married and the father of four young children. The relationship between this married Frenchman and the "foreign" woman scientist was a scandal, which the press and the gossips relished. For a time, Marie even left Paris, seeking peace and safety with scientific colleagues and friends abroad.

In the midst of this turmoil, Marie was proposed for membership in the Académie des Sciences. The Academy, uneasy with the scandal and the associated publicity and with some members extremely vocal in their objections to admitting any woman to membership, selected another candidate. Marie, embittered by this insult, and still angered by the Academy's earlier refusal to admit Pierre, was later to refuse invitations to reapply for admission. It was not until 1945 that the Académie des Sciences would admit a woman to its membership.

THE SECOND NOBEL PRIZE

The Nobel committee, however, was less impressed by scandal than by science and on November 5, 1911, awarded Marie Curie the Nobel Prize in Chemistry, recognizing the work on Polonium and Radium that she had performed after receiving the 1903 prize.

Marie continued to head a large and active research group, with an international group of students and collaborators and

an international reputation. This grew into the Institut du Radium, a facility dedicated to the study of radiation and its uses. Construction on the Institut du Radium began in 1912, with two buildings, one to house Marie Curie's research group and one to house the physicians, headed by Claudius Regaud, who were pioneering the use of radiation in medical diagnosis and in the therapy of cancer. The Institute was completed in 1914, just as WWI erupted.

RADIOLOGY CARS

The war brought another era into Marie's life. She was appalled at the lack of modern medical care available to the wounded soldiers on the front lines. To address this problem, she devised and built "radiology cars," made from donated vans, trucks, and limousines to carry diagnostic radiology to the battlefield. These vehicles not only carried portable fluoroscopes, X-ray units and darkrooms to the medical tents on the front lines and nearby hospitals, along with technicians to operate them and physicians to interpret the films, but also provided the power to operate these machines, as many towns and hospitals in rural France still lacked reliable, standardized electricity.

Marie also established and oversaw programs to train physicians and technicians to operate these units. These programs trained over 400 physicians as radiologists and also trained 800 men and 150 women as radiology technicians. Both Marie and her daughter Irene, now 18, headed radiology teams. Over 1 million wounded soldiers had their care directed by radiographic exams from these units. The success of these units in improving emergency care on the battlefield soon transformed Marie in the eyes of the French public from the scandalous foreign woman into a French patriot and national heroine. Her name became associated

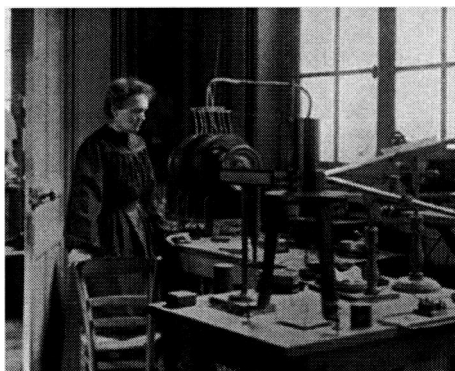


Figure 3. Marie Curie in her laboratory.
(Gerald Howe, Ltd.)

with the medical uses of radiation through this route, as well as through the growing use of radium in the treatment of cancer. Research at the Institut du Radium continued and increased as the group continued to expand to include a cadre of scientists with growing independence and scientific maturity. Even today, many leaders in the radiation sciences and radiation medicine trace elements of their own training to those who studied with Marie Curie and Claudius Regaud.

COMMUNICATING SCIENCE

Marie had by this time realized the importance of communicating directly to the public about the importance of radiation in science and medicine. She gave talks and wrote books for lay audiences including a biography of Pierre Curie [8] and "La Radiologie et la Guerre," which tells the story of the radiology cars and describes the science and technology behind them [9]. One of my favorite plates from this book illustrates Marie's ability to communicate complex ideas through familiar analogies. The picture shows a hand wearing two rings: a gold ring, which casts a very dark shadow, and a ring of similar size made of aluminum, which (being less dense) casts a fainter shadow, and allows the bone in the finger to be

seen passing through the ring. On the wrist is a bracelet with an iron chain (which can be clearly seen), covered by a very thin aluminum plaque (so thin as to be invisible). The bones of the hand and wrist can be seen clearly; the flesh, only faintly. A radiochromometer, a device used to measure radiation dose and energy, is shown beside the hand. This device is now easily understood to be only a series of metal plates of varying density and thickness. Only a woman would think to explain radiation absorption and measurement using jewelry.

Marie Curie also spent increasing amounts of her time and energy raising money for research and promoting science and education. The economy of France had been devastated by the war, as had the facilities and resources of the country. Funds for research were sparse and difficult to come by, even for the Institut du Radium.

An unexpected development aided these efforts. Marie, who hated interviews, agreed to be interviewed in 1920 in her home by Marie Mattingley Meloney. "Missy" Meloney was the editor of a "thoroughly respectable" American woman's magazine called *The Delineator*, published by the Butterick Company. During this interview the two women developed an immediate rapport, which formed the basis for a long friendship. Missy was astounded to learn that the Institute was so poorly funded and, moreover, had almost no Radium beyond the limited supply that Marie had originally isolated during her thesis work, despite the fact that factories around the world were now producing large quantities of this and other radioactive materials for use in science, industry, and medicine using the techniques that Marie had developed but never protected with patents. Missy, a dynamic, energetic, and totally media savvy mover and shaker, decided that Marie Curie needed and deserved better

facilities and equipment to support the research efforts of her Institute, and devised a plan to fund them. She organized a campaign through her magazine, which reached out to women and women's groups throughout the United States to raise \$100,000 to buy Marie Curie 1 gm of radium.

VISIT TO THE UNITED STATES

The campaign was an immediate and overwhelming success. By January 1921, Missy was eagerly planning Marie's trip to the United States to receive the Radium from President Harding in a ceremony in the Blue Room of the White House. The plans grew and grew, ending in a seven-week long trip in which Marie would receive 10 honorary degrees, visit numerous laboratories and factories, and visit several women's colleges, including Smith, Holyoke, and Vassar. The trip also included the largest meeting of American university women yet held. At this meeting, held at Carnegie Hall and sponsored by the American Association of University Women, 3,500 women came to see and hear the heroine they had been hearing so much about in the press. Marie was also to be given the "grand tour" of the United States, with stops at Niagra Falls and the Grand Canyon.

Marie, Eve, Irene, and Missy arrived in New York on May 4, 1921 to begin this whirlwind tour. Marie, not strong and never comfortable with crowds and ceremonies, was exhausted even before the tour began. The limitations of her stamina resulted in the cancellation of some activities and in Irene and Eve serving as her proxies in other functions. Nevertheless, it was a successful trip, which raised the visibility of Marie Curie and her research, raised funds to support the Institut, and also served as a touchstone of encouragement for American women seeking entry

into the still very masculine worlds of science and academia.

MARIE CURIE AT YALE

One of Marie Curie's last stops on this trip was here at Yale. It appears that encouragement for her visit to Yale and the nomination for her honorary degree came from members of the faculty of the School of Medicine, with whom she had communicated about the medical uses of radium and X-rays. While in New Haven, Marie, Irene, Eve, and Missy stayed at the home of Dr. and Mrs. Henry W. Farnum, at 43 Hillhouse Avenue. This house was later sold to Yale, remodeled, and is now the house of the President of Yale University.

Marie Curie's visit to Yale coincided with the June 21, 1921, commencement. A new University president was being installed at the same event; as a result, the commencement ceremonies were larger and more celebratory than usual, with presidents from most Ivy League schools, major women's colleges, and other universities in attendance for the installation ceremonies. The attention of the University community and the media was focused on the presidential installation, rather than Marie Curie's visit. At commencement, Marie Curie was given an honorary Doctor of Science degree. The dedication that goes with Yale's degree [10] is interesting:

Introduction:

Marie Sklodowska was born in Warsaw and has always been a scientist; her father was a distinguished professor and her husband, Pierre Curie will never be forgotten. She was educated at Warsaw and at Paris and has been Professor of Radiology at Warsaw. It is superfluous to mention her discoveries in science and now she has discovered America. She has often encountered dangers in scientific experiments, but nothing so dangerous as American Hospitality; it is to be hoped that she will not be a Woman Killed with Kindness. She is unique. There is only one

thing rarer than genius, and that is radium. She illustrates the combination of both.

President Hadley's dedication:

For the distinguished services that you have rendered to science and the world, we claim the privilege of adding one more to the many honors which you bear with such charm; and to enroll you among our Doctors of Science, admitting you to all its rights and privileges.

AN AMBASSADOR FOR SCIENCE

In the years that followed, Marie Curie continued her work as a scientist and an ambassador for science. Irene Curie became increasingly important to the research effort at the Institut du Radium, receiving her doctorate and often serving as her mother's chief collaborator. Irene married another researcher in the laboratory, Frederic Joliot, and they collaborated on experiments that led eventually to the discovery that Beryllium, when bombarded by alpha rays from a Polonium source, emitted penetrating radiations, which were eventually shown by Chadwick and Rutherford to be neutrons. In 1934, the Joliot-Curies also showed that by bombarding Aluminum with alpha particles, they could produce a radioactive isotope of phosphorus. 1935, Irene and Frederic Joliot-Curie received the Nobel Prize in chemistry for this "synthesis of a new radioactive element."

Eve Curie did not share her family's passion for science or their introspective nature. Instead, she was an outgoing, attractive woman, with a flair for fashion and talent in the arts. She was a fine pianist, and for some time considered a career in music, but instead turned to a career in journalism. Her first book was a biography of her mother, which became one of the most popular books of the Twentieth century.

Throughout her life Marie Curie continued to be active as the head of the research group and as an ambassador both

for her own group and the larger scientific community. Her health continued to decline, with problems including persistent anemia, lung problems, and cataracts, which were probably induced by radiation. With her typical desire for privacy, she hid these problems, and many (including her blindness) were unknown, even to her students, until after her death. Marie Curie died July 4, 1935, at the age of 66. The cause of her death was given at the time as aplastic anemia, but it is now thought that the anemia was actually a secondary effect of radiation-induced leukemia [4].

Marie Curie is still one of the world's most popular scientists, remembered not only for the excellence of her science, but also for her passion for science, her battles to allow women scientists to take their place alongside their male colleagues, her ability to convey science to the non-scientist, and her role in changing education for women. Her position as a role model can be illustrated by a trip to your public library — in my town of Guilford, Connecticut, the library has on its shelves two biographies of Marie Curie written for

adults but eleven different biographies written for children and adolescents. Her legacy is being passed on to another generation.

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